Design Methods and Planning Strategies to Enhance Street Safety in New York City

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Abstract

Streets in the cities are a crucial element of human life. However, it is not safe enough that every year over 37,000 people die in road crashes in the US. The thesis aims to research as a planner, how could design methods and planning strategies enhance street safety in large cities. The research uses mixed methods that combine data analysis and site observation to explore how safety improvement present and influence the condition of streets. Several preliminary models have been conducted by data analysis. Site observation acts as supplementation of data analysis to merge the theoretical model into the practical world and observe the elements that could not be revealed by data. In the end, a framework has created for future improvement and development. Also, there are some limitations to the study that could be improved by future studies.

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Chapter 1: Introduction

Street is a place that portrays an essential role for people and communities. It acts as a crucial transit element, a neighborly territory, a historical carrier and also a playground for children. Donald Appleyard states that the street needs to be livable and become a protector for neighborhoods. (Appleyard, 1981) So safe and accessible are the basic demands of people to the street. However, the traditional street design proposal is automobile dependency that to improve mobility but issues of congestion, pollution, and high accident rate have derived. Street is not only for vehicles. People also are a crucial element of the street: children play on the street; senior rest under the tree; commuter walk at the sidewalk; couple enjoy their time at the corner. A safe and livable street for all kinds of users is desired. Here, the paper is focus on identify design methods and planning strategies could enhance street safety.

Based on New York City, the research will identify the design methods and planning strategies that could enhance street safety in large cities. The preliminary step is understanding the inducing factors of high collision streets. The next step is identifying and selecting the methods and strategies from safety improvement projects in New York City. Then, I use data analysis and site observation to evaluate the influence of different methods and strategies on safety improvement and assess the performance of selected tools from users' behavior and implementation. A framework and recommendation will be synthesized with prioritized planning tools and design methods that could help create a livable, safe street for all kinds of users in New York City and also other large cities.

The significance of this study is we could apply the identified tools in future planning and development to create a livable city with safe active streets for all kinds of users in large cities. As tools and methods are not specific to one city, and the fundamental planning principle is the same, NYC is a start point of the research among large cities in the world. The research will help transportation planners to understand street safety and initiate a safety improvement project with selective design methods and planning strategies from the created framework. This study could benefit the majority of society since people use the street every day as pedestrians, cyclists, drivers, or all of them.

Background

Approximately 1.24 million people die in car crashes annually worldwide. However, wars and murders are only 0.44 million. (WHO, 2013) In the US, over 37,000 people die in road crashes each year, and the fatality rate is 6%. (NHTSA, 2019) The most common causes of accidents are drunk driving, speeding, irresponsible driving, and darkness. How could we from planning and street design solve this problem and improve street safety in large cities where most pedestrian and cyclist accidents happen?

To conduct the research and, New York City has been chosen as a subject for research due to following reasons: improving street safety is one of the emphasis missions claimed by Mayor Bill de Blasio; number of projects have been launched; a diversity of safety analysis has been carried out. The research will base on planning strategies and design methods that New York City has already implemented to synthesize a safety improvement framework for large cities.

In the first place, we need to acknowledge the current street safety overview of New York City. Based on National Highway Traffic Safety Administration's Fatality Analysis Reporting System, the New York City traffic fatality rate is 1.71 deaths per 100,000 residents, which is a quarter of the country's average and ranked 70th in the list of metropolitan areas with the most pedestrian fatalities. However, New York City is the one with the second-highest absolute number of pedestrian fatalities that 143.29, Los Angeles with the highest number 210.71, which makes us could not ignore the safety issue in the large city. (Ascienzo, 2018) Large residential populations, high population density, and a large number of tourists are unique elements for large cities. Because of the enormous population, street safety improvement is crucial in large cities to protect more people's life.

Then based on official reports, the general causes of an accident are driver inattention, speeding and other factors. Driver inattention was contributing to nearly 36% of crashes resulting in pedestrians killed or seriously injured. Pedestrian crashes involving unsafe vehicle speeds are twice as deadly as others; however, most New Yorkers do not know that the standard speed limit for city streets is 25mph. Other factors are crossing-against-signal, left turning, lane changing, and alcohol. The reports also reveal that senior is a majority group of fatalities that 38%, but seniors are 12% of NYC's population. (NYCDOT, 2010)

Also, reports affirm that planners need to pay more attention to pedestrian safety improvement. According to the 2018 New York City traffic crashes data presented by New York City Department of Transportation (Table 1), three-quarters of traffic injury happened to the motorist, but pedestrians account for more than half of traffic fatality. From NYCDOT

Pedestrian Safety Study, it demonstrates Pedestrians that involve in a collision are ten times more likely to die than a motor vehicle occupant. (NYCDOT, 2010)

	Injury	Percentage	Fatality	Percentage
Pedestrian	**10,755**	**18%**	**115**	**57%**
Cyclist	**4,307**	**7%**	**10**	**5%**
Motorist	**45,754**	**65%**	**78**	**38%**
All	**60,816**		**203**	

Table 1: 2018 New York City Traffic Injuries

Nonetheless, the current street design is automobile dependency even in the metropolitan area. If you look at the street's layout of the most major streets in the USA, the auto vehicle is the primary user of roads instead of people. Three to four travel lanes provided with a narrow or high pedestrian density sidewalk. In New York City, at least two travel lanes have provided with a large width that 11'-13'. At the major street like 8th Ave, travel land could even be four lanes. One the other hand, facilities for other users that pedestrians, cyclists, public transport users are restricted. For example, excessive pedestrian density is on sidewalks; bike lanes are fragmented bus lanes are too narrow and not enough street parking space for freight. This high automobile dependency scheme does not facilitate mobility of streets but causes congestion, pollution, and limit accessibility. Multi-modes transportation should be promoted, that could reduce congestion and provide more options. As dangerous factors that motors have been regulated, a safe and livable street will establish for the public. A safe street not only improves public health but also limits economic reduction, improves the quality of life, creates a sustainable city, and promotes equity.

Outline of Research

The thesis consists of six chapters. Literature review will follow this introduction that will review the previous research on street safety and explore current project in New York City and general standard of street design of the United State.

The next chapter would explain design of the research that hypothesis, data souse, location selection and methodology will detailly demonstrate. The fourth and fifth chapter are the major quantitative and qualitative finding of the research. The chapter 4, data analysis, will from two scopes to analysis collision and street improvement in New York City. The citywide scale research will investigate and visualize the feature of existing condition, and the Manhattan intersection scale research will use linear regression model to demonstrate the influence of every design methods and planning strategies for future development. The chapter 5, site observation will act as supplement of data analysis from three sites in Manhattan to observe how safety improvement function in practical and any blind points could not be noticed in data analysis.

The last chapter will discuss recommendations of street safety improvement from my research and reflect on the limitations of this research.

Chapter 2: Literature Review

Research on Safety Improvement

To research on street safety improvement, first, take a look at the history of street safety and the standard of street design. King has a brief introduction of street history that not highway, which receives more historical attention. Streets have become standardized during the industrial revolution, which is still vehicle orient, but the idea of physically separate has immerged. The safety concept was introduced around the 1980s. Soon amount of innovative principles founded like complete street, traffic calming, resilient streets. Kings think streets could be standardized. In his article, he listed eight main concepts for street design and the one related to safety is “Three physical properties of safety: separation, protection and reduction” and “Clear policies and compliance.” (King, 2014) However, Hauer questions about the safety standard for highway design. He claims that the level of safety of roads is unpremeditated that the road in use cannot be safe, “only safer or less so.” (Hauer, 1999)

Hauer raises a question of how to define safety and how we could measure safety. If the definition of safety is unclear, how could the street design standard improve safety? Hauer redefined safety by separate two distinct concepts of safety that include nominal safety and substantive safety. Nominal safety requires a proper behavior of road users, and street design should promote regulation. Substantive safety is a numerical standard that measured by expected crash frequency and severity. (Hauer, 1999) He gives out a new definition of safety and how to apply safety treatment to the streets.

Based on Hauer's definition, nominal safety is the behavior of road users, which could be interpreted by site observation of human activity. Nevertheless, how could we measure substantive safety more comprehensively? Hauer uses crash modification factors (CMF) to exam the width of lane influence on safety. CMF is an indicator defined by the Federal Highway Administration (FHWA) for safety improvement, which could evaluate the effectiveness of safety treatment to reduce the occurrence of the same crash type. (FHWA, 2019) Moreover, currently, most of the statistical analysis of safety only use accident rate, crash frequency as the preliminary representation of safety. Richard provides another measurement in his research. He did not use the accident rate as the dependent variable. By the relationship that limitation of speed could improve safety, he used speed as the preliminary research subject to research how geometric street design could reduce speed and improve safety. (Porter, 2012)

In the NYCDOT report Measuring the Street, the methodology for safety study has been outlined, which is more comprehensive and involve diversity factors. The defining of safety is closed to nominal safety that not only focus on number but also regulation and behavior. First, it states that the metrics of safety include crashes and injuries, users' volume, traffic speed, user satisfaction and environmental, and public health benefit. Designing a safer street, building public spaces, improving public transportation, reducing delays, and speeding all could finally end on road safety improvement. The street redesign methods include simplified intersection, create public plazas, transit signal priority, etc. (NYCDOT, 2012)

A pedestrian-friendly and safe urban street could directly link to highly desirable social outcomes like economic growth and innovation, improvements in air quality, and increased physical fitness and health. Dumbaugh states

> "Livable streets seek to enhance the pedestrian character of the street by providing a continuous sidewalk network and incorporating design features that minimize the negative impacts of motor vehicle use on pedestrians." (p.1)

Dumbaugh also researches the influence of street trees on safety. He rejects the point side tree is danger factors. American Association of State Highway and Transportation Officials (AASHTO)'s Roadside Design Guide that states a clear roadside is the central authority on the design of safe roadside. (AASHTO, 2002) Dumbaugh thinks that the use of aesthetic streetscape treatments could enhance the livability of urban streets, and roadways should link to this environmental context. (Dumbaugh, 2005)

Urban Street Design Guideline

Figure 1: NACTO street's recommendation

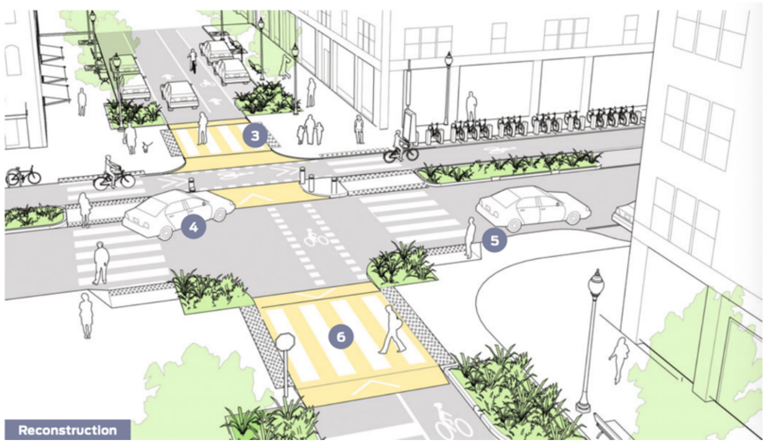

Figure 1.2: NACTO intersection's recommendation

Urban Street Design Guide is a guideline published by the National Association of City Transportation Officials (NACTO) with detail design principles of city streets and public spaces to create a livable, safe, and accessible city. The guideline focuses on two major components of streets: street and intersection. The design guide has comprehensive detail and information from 1-way street to transit corridor, from the width of land to stormwater management. NACTO states

> "streets also are public space. Great streets are great for businesses, and we should design for safety. intersection design should facilitate visibility and predictability for all users, creating an environment in which complex movements feel safe, easy, and intuitive."

NACTO guideline has act as a blueprint for 21st century streets that outlines a clear vision for complete streets and a basic road map. The design aims to not only provide transit in communities but focus on safety and sociality of communities. The *Urban Street Design Guide* is the principles and practices of the nation's engineers, planners, and designers working in cities today. Both public and private sector use it as basic guideline for street design

In summary, NACTO wants to transform streets to more multi-mode transit, ecosystems friendly, safety for various users. Within Design Guideline, the following recommendations or principles are highly related to safety improvement, which cover all the elements of streets:

- Lanes greater than 11 feet should not be used as they may cause unintended speeding and assume valuable right-of-way at the expense of other modes.
- Sidewalks have the desired minimum through a zone of 6 feet and an absolute minimum of 5 feet.
- Curb extension has a diversity of benefits: tighten intersection curb radii, encourage slower turning speeds, increase the visibility of pedestrians
- Use of speed hump, speed table and speed cushion for speed control
- Crosswalk should have high visibility and accessibility.
- Design intersections to be as compact as possible

Research Framework and Background.

<u>Vision Zero</u>

Vision Zero program is established in 2014 by Mayor Bill de Blasio to eliminate traffic deaths and severe injuries on NYC streets by 2024. It is based on a similar program that was implemented in Sweden. Previous to its inception, a certain number of injuries and fatalities on our streets and highways were expected and accepted. However, Vision Zero assumes crashes can be prevented by regulation and design. (NYCDOT, 2014) The city has worked hard to drive down injuries and fatalities on New York City streets. From lowering the speed limit to 25 MPH, dramatically expanding traffic enforcement of the most dangerous infractions, to pushing through street redesigns, the city has taken an expansive approach to improve safety on New York City streets. (NYCDOT, 2019)

Complete Street

Governor Andrew M. Cuomo signed the Complete Streets Act on August 15, 2011, requiring state, county, and local agencies to consider the convenience and mobility of all users when developing transportation projects that received state and federal funding. As stated in the Act, Complete Streets will contribute to a "cleaner, greener transportation system," and "more citizens will achieve the health benefits associated with active forms of transportation while traffic congestion and auto-related air pollution will be reduced."(NYSDOT, 2019) According to the New York State Department of Transportation, Complete Street aims to enable safe, convenient travel and access to all groups of users through four project elements: pedestrian infrastructure, traffic calming, bicycle accommodations, and public transportation accommodation. (NYSDOT, 2019) From review Amsterdam Avenue case, Complete Street roadway design features include sidewalks, lane striping, bicycle lanes, paved shoulders suitable for use by bicyclists, signage, crosswalks, pedestrian control signals, bus pull-outs, curb cuts, raised crosswalks, ramps and traffic calming measures. (NYCDOT 2019)

Chapter 3: Research Design

Methodology

The research method is mixed methods that combine quantitative analysis and qualitative analysis. Before dig into two analysis, the definition of accident needs to be clear. In the research, accident is referring to collisions happen between vehicles and vehicles, vehicles and pedestrians, and vehicles and cyclists on the urban street. More specific, the accident is collisions involve vehicles and happen on travel lanes of city landscape.

The quantitative analysis has two parts that include NYC's overall analysis and influential regression model, and the qualitative analysis lead by a site visit of five selected locations within Manhattan, NYC. The NYC overall analysis is based on the New York City traffic crashes data to interpret the general safety condition and predict the future time series of New York City. The influential regression model is used to determine the safety crucial design element and create the best model for future improvement and development by machine learning. The site observation aims to assess the performance of selected tools from users' behavior and implementation. The unit of both types of research is the intersection of Manhattan. Since Manhattan has four times as many pedestrians killed or severely injured per mile of street compared to the other four boroughs (NYCDOT, 2010) and most safety improvement is happening at the intersection like pedestrian refuges and curb extension. Also looking at Vision Zero View's collision map, most accidents are happening at intersection. For different research, sample selection will be varied that detail will be explain in each section below.

Quantitative Analysis

As mention before, the quantitative analysis composed of two parts that NYC's overall analysis and influential regression model. The two analyses with different research purposes, different research scope, and different data sources. Part 1 is a general analysis and part 2 has a high influence on the final framework.

Part 1: NYC Overview

NYC analysis is a more general background analysis for the research. Because this is a general analysis, the research scope is citywide rather than intersection, and the timeline is from 2012 to 2019. The purpose of the research is to summarize features of accidents like borough, time and reason of accidents to provide necessary information for planners could better understand the condition and provide recommendations. A primary time forecasting will conduct for planners has a first impression of potential future planning. The source of data is the New York City Motor Vehicle Collisions - Crashes presented by the New York City Police Department from 2012 to 2019. The useful variables from the data frame include time, number of person/ pedestrian/ cyclists injured or killed, borough, reason and collision and type of vehicle. I will visualize the result to have a better interpretation of the analysis.

Part 2: Regression Model

The regression analysis aims to create the best model for future improvement by machine learning. The analysis is focused on to exam the level of influence of design methods and planning strategies on cause of accidents and by machine learning to create the best model with selected variables and magnificent.

For quantitative research, the hypothesis is crucial. The data model and variable are derived from a hypothesis. My hypothesis for the research is that Does street design improvements affect the safety condition of street? From hypothesis, my research model is

Safety condition of street = f (street design improvement) + Error

Time is the control factor of research. By selecting the accidents that happen only in 2019 creates a longitudinal comparison of improvement methods.

From the model, the safety condition is the dependent variable, which is represented by the number of people fatality or injury at a collision in 2019. The regression analysis will separately focus on the cause of injury and the cause of fatality. Number of fatality and injury are the most direct index to reveal the safety condition of street. High number means more dangerous that the intersection needs more attention from planners. Definitely, major corridor with high vehicle flow which collisions are more likely to happen. But this is not the excuse higher fatality and injury. More attention and better design are desired for those intersection. To emphasis the result, the research is focused on the most representative 95 intersections of Manhattan, among around 250 intersections of Manhattan, which has fatality or more than ten injuries in 2019.

The data source is New York City Department of Transportation and Google (see Table 2). The accident information, including number of injuries and fatalities, is from the New York City Vision Zero project's official website Vision Zero View which is published by the New York City Department of Transportation. The source of independent variables is both Vision Zero View and Google Map 2020 satellite view and 2019 street view. To ensure the accuracy of research, as much as design improvements with available data set that could been illustrated at intersection have been included as independent variables like signal intervals, lanes layout, intersection design, and zoning regulations. The condition of streets like size and number of sidewalk/travel lanes/parking lanes/ bus lanes/ bike lanes, presence of refuge, and curb extension could manually collect from Google Map. Some street improvement projects like signal interval enhanced crossing, neighborhood slow zone and safe street for senior has been published by the New York City Department of Transportation. The unit of research is the intersection in Manhattan since most design improvements could illustrate at the intersection scale. The lane information is collected from the section view of comparatively busier and high-flow's major corridor within two streets of the intersection. Table 2 illustrates the summary information.

Table 2: Source of Data

Data source	**New York City Department of Transportation (NYCDOT) and Google Streetview**
Unit of research	Intersection in Manhattan
Sample Size	95
Sample Selection	With fatality or more than ten injuries
Research Year	2019
Dependent Variables	Total number of injuries and total number of fatalities at the intersection of 2019 (detail information in Table 3)
Independent Variables	Listed in Appendix 1 with unit of measure and data source

Some special notices of independent variables are the 0.5 index. The presence of refuge and curb extension and others dummy variables will record as 1, otherwise as 0. Some 0.5 has given to some variable, which means the implementation of design only on some parts or not meets the standard. For example, figure 2 has shown the pedestrian refuge at 85th street and Amsterdam avenue. The pedestrian refuge only painted with few handrails that could not operate as perfect as well implemented refuge, so recorded as 0.5.

Figure 2: Example of 0.5 pedestrian refuge

Qualitative Analysis

Site observation is a complement of data analysis that on-site use qualitative method to exam the performance and influence of safety improvement. The observation objects are focus on the subject lacking numeric information like the reaction of the driver to the improvement, the behavior of pedestrians, the activity of sidewalk, and vendors. An on-site observation could directly reflect the impact of improvement rather than data. Following is the subline need to record：

- Quality of implementation of improvement
- Quality of street condition (pavement, planting, light, and sign)
- Travel speed of the vehicle
- Sidewalk condition (high or low density)
- Pedestrian behavior at an improvement point
- Cyclist behavior at improvement point
- Motorist behavior at improvement point
- Activity on the street

Three locations have been chosen: Broadway between 145th Street and 155th Street, , Amsterdam Avenue between 79th Street to 90th Street, and 8th Avenue between 34th Street and 45th Street. The standard to choose those locations has finished safety improvement projects, different land use purpose, major corridor, and located in special zoning. Three locations all have an implemented Complete Street project and located on a major corridor. The primary distinction of five sites is different land use: 8th Avenue is around the principal commercial center of New York City. Broadway between 145th street and 155th street and Amsterdam Avenue is in the residential neighborhood with small retail or restaurant on the side.

All site observations take place on a sunny Saturday afternoon, which the time most people will come out for relaxing, leisure, and entertainment activity that street full of different age groups users. Although the research area is a range of streets, the observation is still focused on the intersection. I have spent 15 to 20 minutes on each site that walk along the primary corridor and stop at each intersection to observe the layout, implementation of projects, and behavior of people cyclist and vehicle.

Apart from listing five sites, a summary of some other sites with unique features that will induce accidents will illustrate in the end. The observation is from Google Map's street view since I have visited all 100 the most dangerous interaction in New York City for data collecting. Some outstanding features have been summarized.

Chapter 4: Data Analysis

Part 1: NYC Overview

NYC overview analysis is a statistical analysis with visualization of New York City from 2012 to 2019. The research will provide planners with the background of the collision condition in NYC. The analysis includes four parts: injury and fatality, cause of collisions, timer series and forecasting.

Injury and Fatality

Injury and fatality analysis separate user groups that total persons involved in accident, pedestrians and cyclists to illustrate the magnificent and distribution within five boroughs of New York City.

The number of persons includes all the user groups that motorists, pedestrians and cyclists involved in accidents. The analysis provides a general impression of the situation. Figure 3 shows the number of persons injured in five boroughs. From the figure, we could summarize that from 2012 to 2019, eight years, most collisions only have one injured, but the maximum number of persons injured in one collision is 31. This mean only one injured is general of accidents but extremes happen. The extremes are the feature that we need to eliminate. Also, Brooklyn has with the highest number of persons injured; Queens is the next and Staten island is the last one. The result may relate to the population size of each borough.

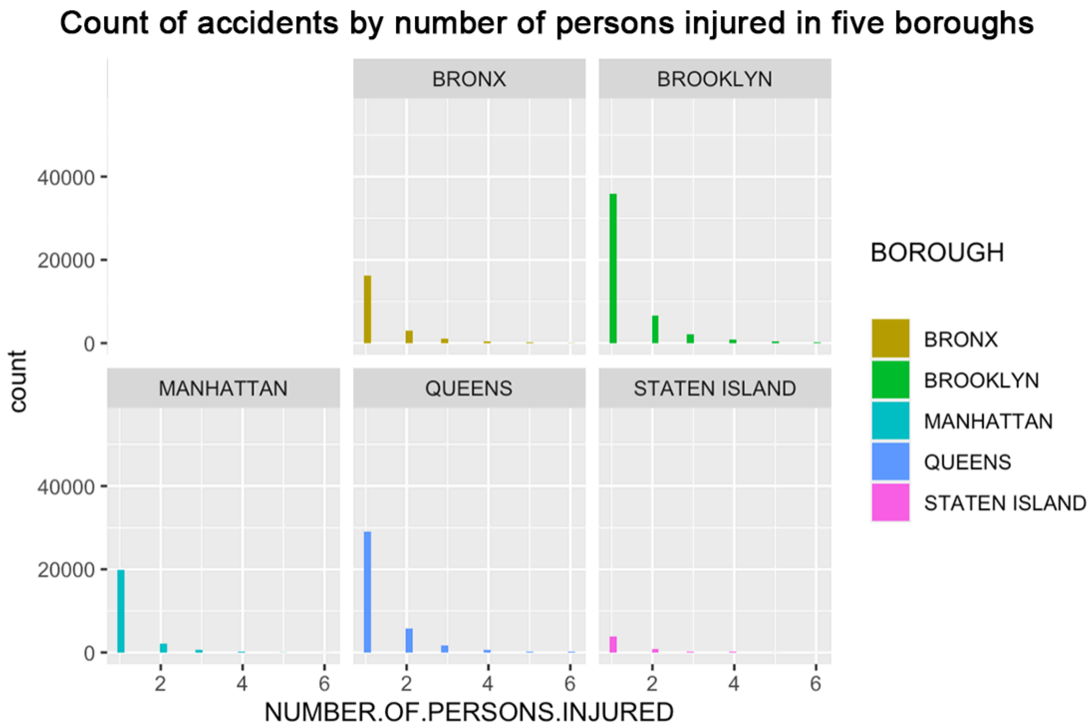

Figure 3: Accident counts by number of persons injured in five boroughs

The number of pedestrians injured is demonstrated in figure 3. The magnitude of count of pedestrian injured is half of persons injured that the average number five borough is around 6,000. However, by compared Figures 3 and 4, the ratio of pedestrians injured in Manhattan is much higher than the other four boroughs that around 40%. The analysis is same with the data present by NYCDOT in literature review. This might relate to Manhattan is more walking-friendly than other boroughs that depended on vehicles. However, once pedestrians involve in an accident, they are with much higher probability be killed than motorist. So, improving street safety condition in Manhattan is more critical than other four boroughs.

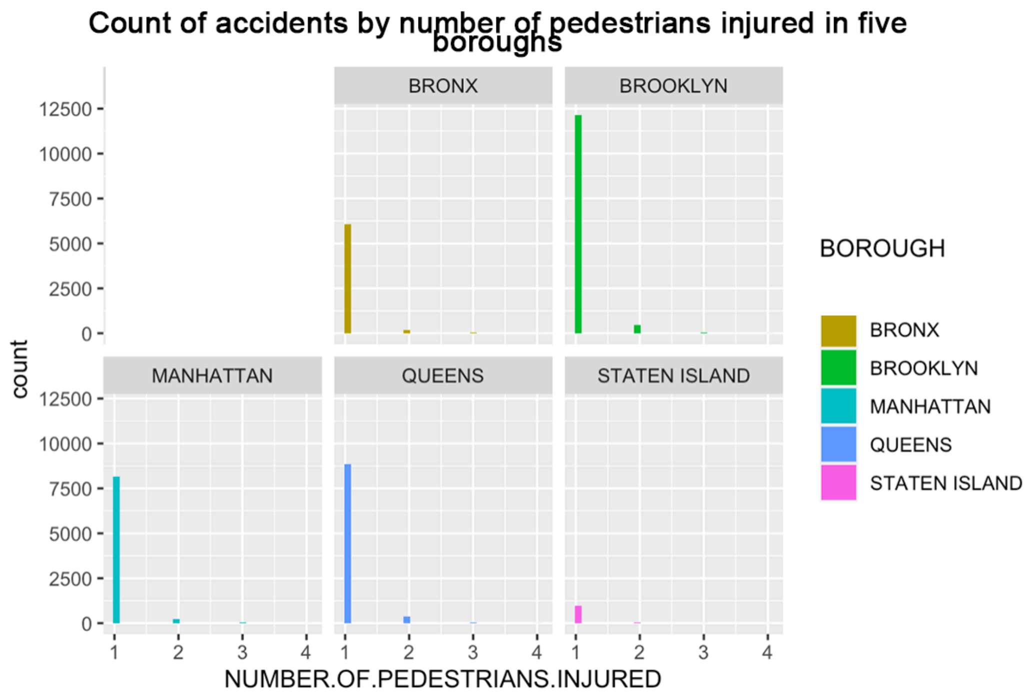

Figure 4: Accident counts by number pedestrians injured in five boroughs

The number of cyclists injured in five boroughs (figure 5) demonstrates that the magnitude of this category is similar to pedestrians. However, the total number of cyclists is must fewer than pedestrians, that means the rate of injured cyclist must higher than pedestrians. Cyclists are the most dangerous groups and need more attention from planners.

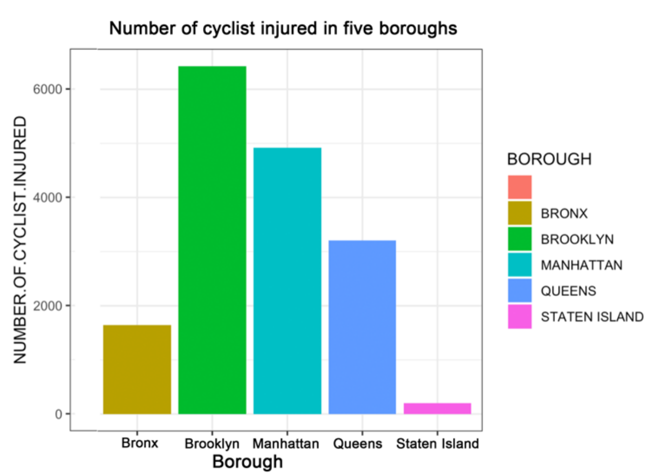

Figure 5: Number of Cyclist injured in five boroughs

After the injured analysis, fatality is another crucial factor for safety, which is not as common as injured but directly threaten human life. Figure 6 shows the number of persons/pedestrians/cyclist fatalities in five boroughs. The total number of fatalities is around 0.01 of the number of injured with similar distribution patterns within boroughs. The magnificent is almost the same with injured that the number of pedestrians killed is half of the number of persons. Compare to other boroughs that the number of cyclists killed is 10% of the pedestrians, Brooklyn has an abnormally high frequency that the number of cyclists killed is quarter of the pedestrians. This reveals Brooklyn need high attention on cyclist's safety which is same with current regulation that bike priority areas are clustered in Brooklyn and Queens. Fatality reveals more serious problem of street safety than injuries.

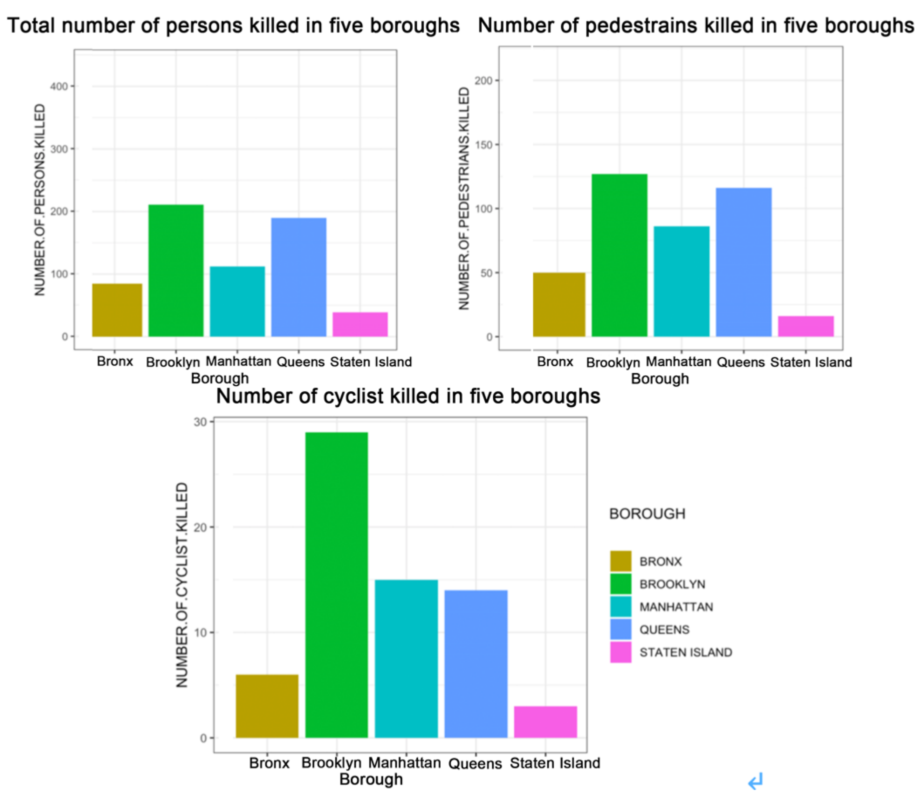

Figure 6: Number of persons/pedestrians/cyclist fatality in five boroughs

Cause of Accident

Based on New York Police Department's Motor Vehicle Collison's Reports, Table 3 is the top 11 reasons to cause an accident that has a frequency of more than ten thousand times. From the listing, the severe cause of accidents is driver inattention, which accounts for around a quarter of accidents. Other reasons we could avoid by planning strategies are failure to yield, turning improperly, and speeding. Those causes of accidents could be averted by intersection improvement and regulation.

Cause of accident	Frequency	Ratio
Driver inattention	241162	23%
Following too closely	84362	8%
Failure to Yield Right-of-way	69489	7%
Backing Unsafely	47001	4.5%
Passing or Lane usage improper	39968	4%
Unsafe Lane Changing	32182	3%
Turning improperly	26740	2.5%
Traffic control disregarded	17647	2%
Driver inexperience	16798	1.5%
Reaction to Uninvolved Vehicle	14609	1.3%
Unsafe Speed	13689	1.3%
Alcohol Involvement	10947	1%

Table 3: Cause of accidents

Types of vehicles that have high frequency involved in an accident also have been analyzed. The result shows that apart from passenger vehicles, which account for three-quarters of accidents, taxi, pick-up truck, bus, van, and bike usually involves in an accident. So the further recommendation will focus more on the large size vehicles and bikes.

Time Series & Forecasting

The time series analysis has two parts that time with high frequency of accidents in a day and tendency among years. For the day time analysis, it has short-term analysis that only data of

2019 and a long-term analysis that data from 2016 to 2019. From short-term analysis (figure 7), accidents with injury happen around 10am and 10pm, and accidents with fatality more likely to happen at 5:30 am. However, the long-term analysis (figure 8) reveals different results that injured accidents happen with three peak times that 7:30am, 12:00pm and 5:00pm, which mostly are commute time. The peak crash time for accidents with a fatality is around 3pm. The completely distinct results from two time periods are impressive that times are not concentrate together. The reason of this result might relate to special conditions of each year like weather and events. Because the short-term result only represent condition of one year, the long-term result is more valuable that large sample set could reduce error. Since the results of fatality time are only two, planners could consider both times. For injured time more analysis needs to involve, but based on current research, the long-term analysis is more valuable and practical that accident happen on commute time and noon.

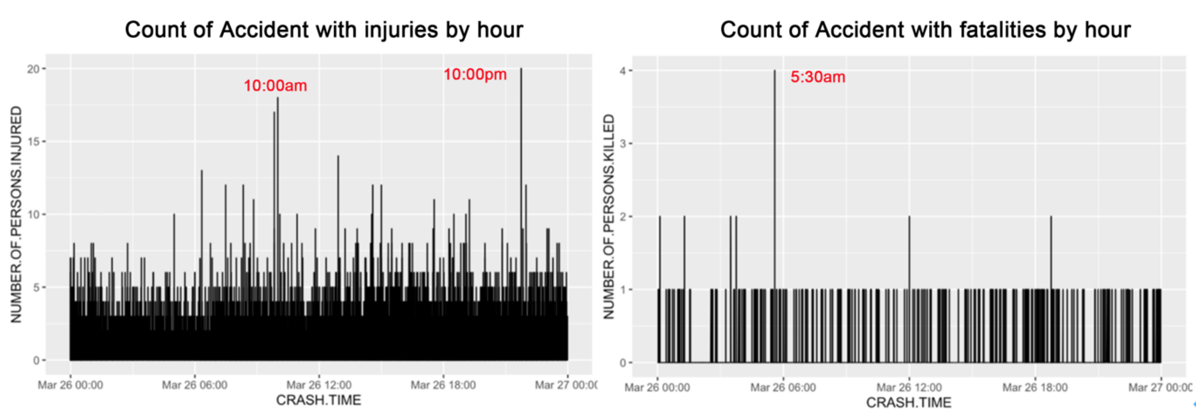

Figure 7: Short-term day time analysis (2016-2019)

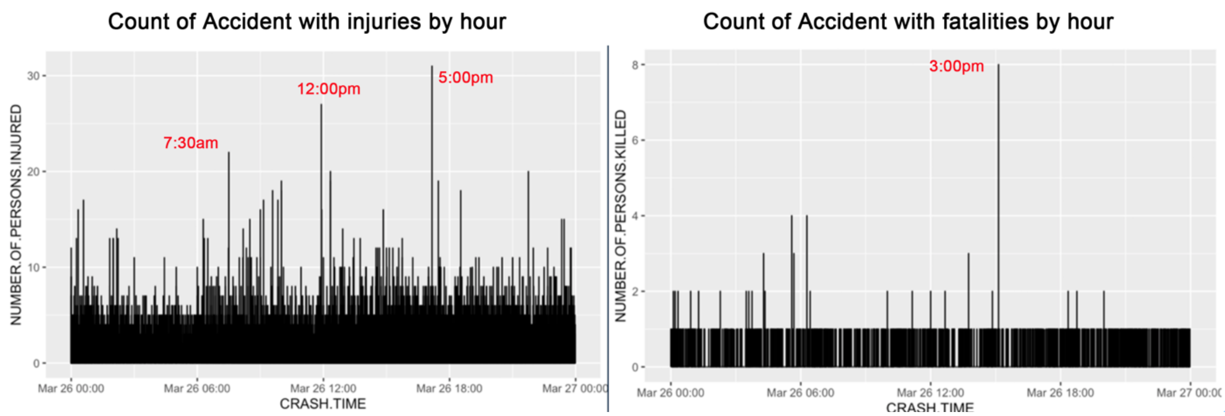

Figure 8: long-term day time analysis （2016-2019）

The tendency analysis by year could demonstrate trend in a year to limit error of season and weather and also help predict future development. Figure 9 illustrate the tendency of injure and fatality from 2016 to 2019. Both of them are not a straight or smooth line with lots of fluctuation. Each year there might be an increase and decrease due to weather and other factors. From graphic, we could summarize after implement of improvement, the safety condition does not have a remarkable reduce. For example, the frequency of injured has an increasing

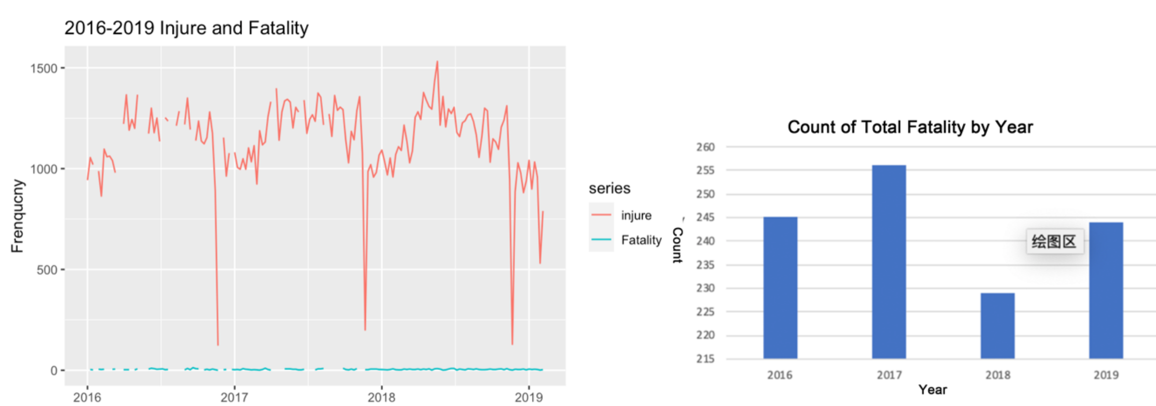

Figure 9: Tendency analysis of injure and fatality from 2016 to 2019

tendency in the first half-year of 2019, which after four years of safety improvement implemented. However, the line has suddenly dropped after and reach another valley. The fatality chart also shows the fluctuation of the accident that 2018 with the lowest number but 2019 raised again. From these two-tendency analyses, forecasting could be conducted (Figure 10). The mean and naive forecast stays at the same level, but seasonal naive increase will occur. The increase in first half year is similar to 2016 to 2019 which is a normal phenomenon. stable mean and naive forecasting predict safety condition will not deteriorate in the future. But planners and engineers still need to work hard on the project to ensure safety condition continue to improve in the future.

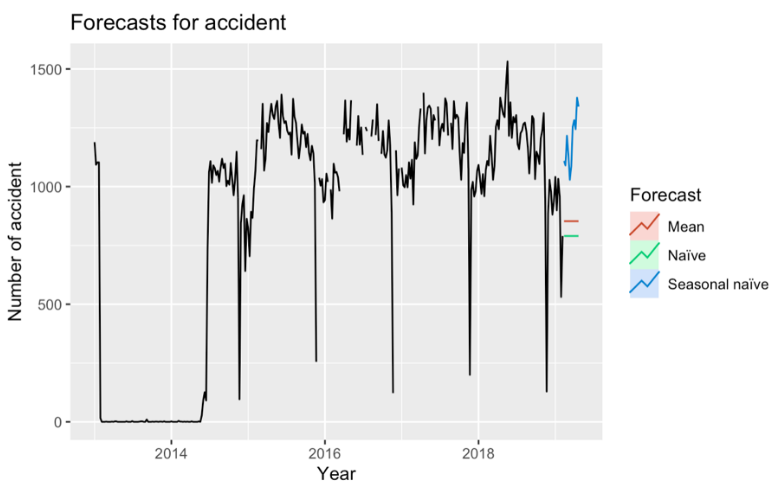

Figure 10: Forecasting

Part 2: Regression Model

Hypothesis

Creating a regression model, the fundamental step is establishing a theory for the hypothesis that create the causality between dependent variable and independent variable needs to meet the prerequisite of precede time order, covariance and non-spuriousness. For this research, the research question is how the planning strategies and design methods influence the street safety condition? From the research question, the null hypothesis and alternative hypothesis could be established that

- Null Hypothesis (H0): safety condition at an intersection is not influenced by planning strategies and design methods.
- Alternative Hypothesis (H1): safety condition at an intersection is influenced by planning strategies and design methods.

After the establishment of the hypothesis, the next step is determining the dependent and independent variables. To ensure the accuracy of the research, there are two dependent variables that number of injuries and number of fatalities. Because of two dependent variables, two regression models will be established for each variable. The independent variable that planning strategies and design methods will explain in the next section.

Planning Strategies and Design Methods (Independent Variables)

In the literature review chapter, the primary planning strategies and design methods of NATCO and NYC have been demonstrated. Here, selected variables will be used as independent variables to exam the hypothesis. The reason for selection is the availability of data and the significance of the variable. Below is the list of 14 independent variables has been applied in the regression model, which include street design standard, design methods, and planning regulations (Data source and unit of measure see Appendix 1)

- Sidewalk size: the average size of the sidewalk among two side
- Number of the travel lane
- Travel lane size: the average size travel lane

- Number of the parking lane
- Parking lane size: the average size travel lane
- Bike lane size: the total size of the bike lane at the intersection
- Bus lane size: the total size of the bus lane at the intersection
- Extra turning lane (Dummy variable): presence of an extra turning lane at the intersection is 1. If vehicle stop at the center of an intersection for turning but without an actual turning lane, it will record as 0.5
- Protected bike lane (Dummy variable): Bike lane separats with travel lane by green buffer, parking lane or drawn buffer. Physical separation like green buffer or parking lane recorded as 1; drawn line buffer is 0.5.
- Pedestrian refuge (Dummy variable): presence of pedestrian refuge at the intersection is 1. If refuge only is drawn box, it will record as 0.5.
- Curb extension (Dummy variable): present of curb extension at the intersection is 1. If extension only applies to one curb at the corner, it will record as 0.5
- Pedestrian lead interval signal (Dummy variable): it is the signal that allows pedestrian across the street ahead than vehicles. If presented, it will record as 1; if not, as 0.
- Arterial slow zone (Dummy variable): the planning regulation apply on the highest crashes' streets with treatments of lower speed limit, change signal timing and improve sign. If located in the zoning area, it will record as 1; if not, as 0.

- Safe streets for seniors (Dummy variable): the planning regulation with the selected region for improving the safety of older New Yorkers. If located in the zoning area, it will record as 1; if not, as 0.

After confirming the independent variable, a regression formation could be generated:

$$\mathrm{Y} = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \beta_5 X_{14} + b$$

$$\text{Y: number of injury, number of fatality and accident score}$$

$$X_1 - X_{14}\text{: Independent variable}$$

Correlation

To establish a regression model, first need to know the correlation between each numeric variable.

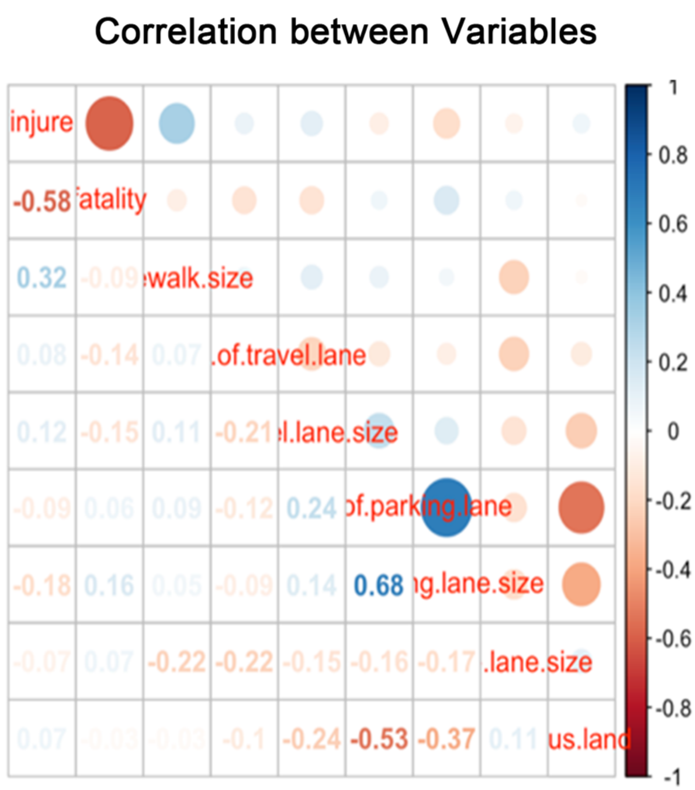

Figure 11: Correlation

From Figure 11, the correlation between each variable has been demonstrated. The first impression is that the correlation among 16 variables is not highly related to each other that most with value smaller than 0.2. Injure and fatality has a high negative relationship among variables. The number of parking lane has a high correlation with parking lane size, but on the other hand, the number of travel lane do not have high relationship with travel lane size. Another impression point is the number of parking lane is a negative correlation with the bus lane. This mostly small correlation result means there is no relationship between variables, or high multicollinearity present between variables. To ensure the statistical significant, the regression model needs to select the most representative variables for independent variables to avoid multicollinearity and error.

Linear Regression Model & p- value

To establish the regression model, I follow the three steps for both dependent variables:

1. Run the model with all independent variables and test p-value of each value:

   when p value > 0.05, the variable is relatively useless for the model

   when p value < 0.05, the variable influences the model

2. Use a stepwise selection to establish the final model that could best represent the dependent variables

3. Use the Akaike Information Criterion (AIC) to select the relative importance variables.

Form the preliminary linear model, when the number of injuries and number of fatalities plays as dependent value, the results of p value are different (Table 4 & 5). The model of injury shows that sidewalk size, pedestrian refuge and safe street for seniors has high influence. The model of fatality shows the protected bike lane, extra turning lane, pedestrian refuge and curb extension is significant. This might because different design methods and planning strategies has different targets. Some improvements limit both injuries and fatalities; others only limit one.

	Standardized Coefficient	**P value**	**Significant**	**Direction of change**
Sidewalk size	2.32671	0.000986	***	Worsen safety
Pedestrian refuge	-7.89704	0.011285	*	Improve safety
Safe streets for seniors	-2.55915	0.0653	.	Improve safety

Table 4: Number of injuries' P value

	Standardized Coefficient	**P value**	**Significant**	**Direction of Change**
Protected bike lane	0.0277	0.00339	**	Worsen safety
Parking lane size	0.230854	0.00467	**	Worsen safety
Pedestrian refuge	-0.005844	0.01399	*	Improve safety
Curb extension	-0.185453	0.01751	*	Improve safety
Extra turning lane	-0.229825	0.04470	*	Improve safety

Table 5: Number of fatality's P value

In summary, form linear regression model, sidewalk size, pedestrian refuge, safe streets for seniors, protected bike lane, pedestrian refuge, curb extension, extra turning lane and bike lane size are the useful variables. From the coefficient plot (Figure 12), it has reveals fatalities' model is concentrate around zero. This is because the mean value of number of fatalities is 0.3 that too small so it is not large enough to show the magnificent. But number of fatalities still is a crucial element from piratical view, the dependent value could not be dropped. The injuries model reveals most independent variables has a positive influence on safety improvement. But partial implement protected bike lane even worsen the safety condition. The first question has raised from data analysis. This question I will try to find solution from site observation in the next chapter. Another issue of linear regression model is, 14 independent variables are too many for future development. I need to filter down the independent variables to create a more concise model for future improvement, then Stepwise Selection involved.

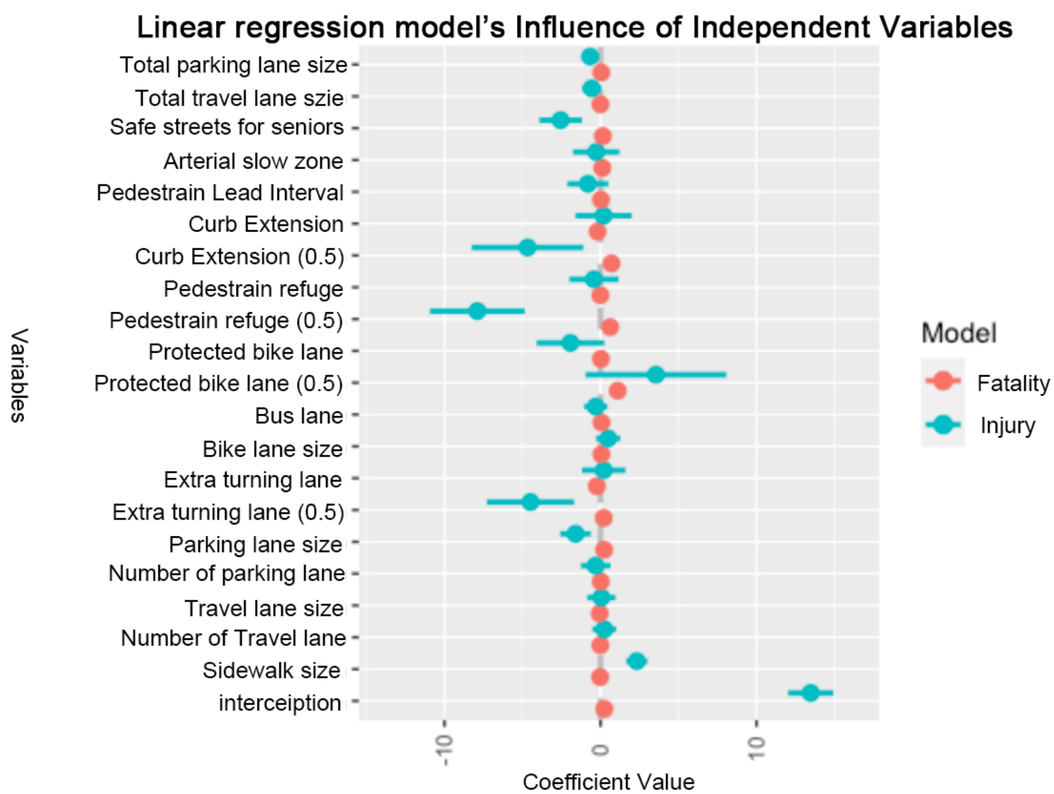

Figure 12: Linear regression coefficient

<u>Stepwise Selection</u>

From the linear regression model, preliminary useful variables and relationships have established, but is there a better model exist? Could we continue to improve the model? The stepwise selection will help solve the problems. Algorithms will facility us to produce the best model.

From stepwise selection the final model for number of injuries is:

injure = 12.18 + 1.94 sidewalk size – 1.09 parking lane size – 7.5 pedestrian refuge – 2.2 safe streets for seniors

From equation and figure 13, large sidewalk size will induce injury, pedestrian refuge, parking lane size and safe streets for seniors could efficiently reduce injury. Pedestrian refuge is the design method improve injuries safety condition most. The result is different than the expectation that sidewalk size will worsen then safety condition. Although the analysis shows sidewalk will induce injury, it still is necessary elements of street life and influence pedestrian density. The second question about data analysis has been raised. Let’s left it on the table and take a look at fatalities’ model.

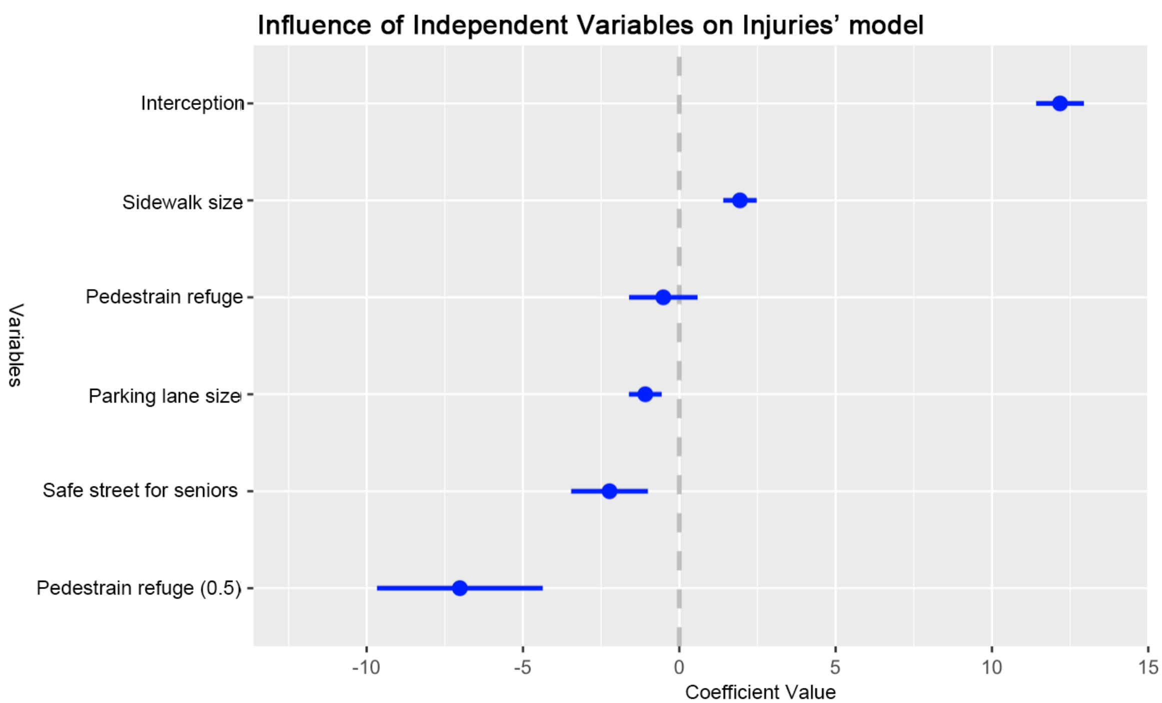

Figure 13: Coefficient Plot of Injuries

The final model for number of fatalities is fatality = 0.34 + 0.13 parking lane size – 0.2 extra turning lane + 1.4 protected bike lane – 0.06 pedestrian refuge – 0.1 curb extension

Fatalities' equation and figure 14 show that full implemented pedestrian refuge, curb extension and extra turning lane could reduce fatality. However, all the feature with record index of 0.5 will increase fatality, which is the partial implementation, like curb extension only on one corner or protected bike lane without physical separation. This is similar to the first question from linear regression model that partial implemented improvement could worsen safety condition.

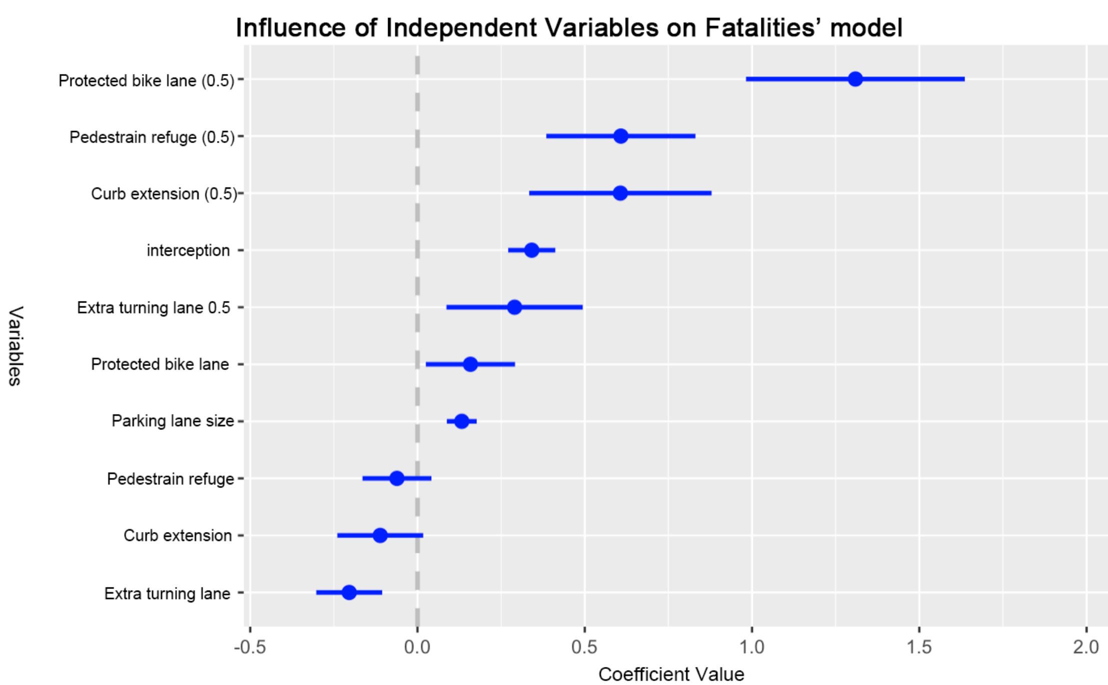

Figure 14: Coefficient Plot of Injuries

<u>Akaike Information Criterion</u>

Last, an Akaike Information Criterion (AIC) could help to select the relative importance variables. Figure 15 demonstrates the result that sidewalk size is the relative importance variables for the number of injuries and the protected bike lane is crucial for the number of fatalities.

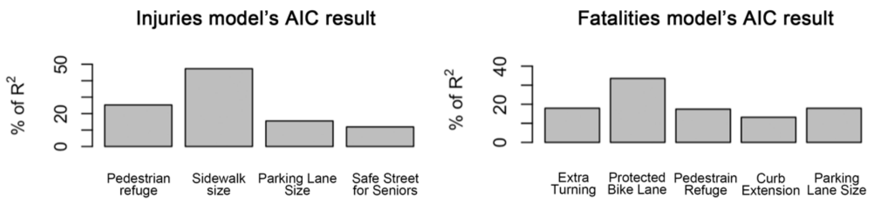

Figure 15: AIC Result

Conclusion

In conclusion, the regression model has provided useful information but also raised two crucial questions. First, the basic injuries' and fatalities have been created that provide planners a preliminary framework for future development. Perfect implemented pedestrian refuge, extra turning curb extension, and the protected bike lane could improve street safety conditions. On the other hand, two questions have generated from data analysis that

- Large sidewalk size and parking lane size will worsen the street safety condition. On the theoretical level, this is correct. The most safety condition is that there is any traffic in the world. A larger sidewalk means higher traffic flow, which will create accidents and worsen safety. However, this is counter wise with the practical. We are living in a world that could not survive without transition. Sidewalks, travel lanes, and parking lanes are essential elements of our daily life.
- All the features with a 0.5 index that partially implemented will worsen the street safety condition.

Data analysis is only a theoretical framework. For comprehensive research, the framework needs to be practical and reasonable with the real world. In the next section, several site observations have been conducted with these two questions from data analysis. I will try to find answers from the real world.

Chapter 5: Site Observation

From the Literature review, Hauer has used two terms to define the safety that nominal safety and substantive safety. Only with results from data analysis, it is substantive safety based on numeric information. Behavior and communities are the crucial elements of safety measurement that close to nominal safety. However, behavior and community information are hard to measure, so site observation is necessary at this point. In this chapter, I will conduct three site observations at two different land use locations that residential study site of Amsterdam Avenue between 79th Street to 90th Street and Broadway between 145th Street and 155th Street; and commercial study site 8th Avenue between 34th Street and 45th Street. Site observation is conducted after data analysis, so I was visiting the sites with listed two questions from the last chapter, and I will try to answer those in the end.

Land Use: Residential

<u>Amsterdam Avenue between 79th Street to 90th Street</u>

Project Description

Amsterdam Avenue's project addresses safety problems along a high crash corridor that more than 50 people killed or severely injured over the course of 5 years including both pedestrians and cyclists. Meanwhile, the project aims to reduce the gap in the bike network in west Harlem that neighborhood completely without bike facilities. Factors causing high crash rate on the corridor are high off-peak speed, high speed turns, long pedestrian crossing and undefined lane assignment (NYCDOT, 2019). Other elements that need to be improved are no dedicated space for bikes, peak hour congestion and lack of commercial loading. The project aims by a redesign of street and intersections to fix those problems.

Figure 16: Amsterdam Avenue between 79th Street to 90th Street study area

The proposal of Amsterdam Avenue development includes reassignment of lanes function and lane size, intersection redesign and including bike lanes in each direction. I focus on the intersection improvement within this proposal. The proposed design methods of intersection improvement include curb extensions, turn treatment and pedestrian island. Curb management is crucial in street design that defines curb activity and provides safety. Curb extension could improve alignment, tighten turning radii, discourage speeding, shorten crossings and enhance visibility. Turn treatments include an extra turn lane and an extra turning light to reduce back pressure to drivers and create simpler and safer left turns. Plenty of pedestrian islands in NYC is lack of maintenance but this extra island could provide safety to pedestrians. Pedestrian islands could reduce the size of travel lane to limit speed and enlarge visibility of driver, and also provide extra landing space during the crossing. Also, green features of the island could separate pedestrian from vehicles and protect the environment and community.

Site Observation

Figure 17: Paint of crosswalk has disappeared

Since it is in residential area during weekend, the most direct impression of the area is it is really crowded that sidewalks are full of family, children and also some seniors. The frequency of sidewalk usage is high. Another feature of the site is diversity users and function. Because site is close to central park, cyclists and runners has usually appeared. Also, kids run and play balls on the street; seniors chat and play the chess under trees; and young site in the outdoor area of cafe. However, several issues are also presented that could not be demonstrated by data analysis. First is the unexpected seating area on the sidewalk from side vendors. Although sidewalks at Amsterdam Avenue is really large, some section of street is used by restaurants as their seating area with taken at least half of sidewalk. Therefore, the size of sidewalk has reduced and make it become really crowdy. Family could not walk side by side and at some part, people need step out of curb. Second, because travel lane is not in a high use, pedestrian always ignore crossing signal when cross both long-distance and short-distance streets. Last potential problem of the site is lack of maintenance. Complete street project is finished around 2016, but the painting of bike lane, crosswalk and curb extension is in high required of maintenance.

Broadway between 145th Street and 155th Street

Figure 18: Broadway between 145th Street and 155th Street study area

Project Description

` The site is located in the residential region of Upper West of Manhattan. Intersections at 145th and 152nd street are with high crash data among 108 pedestrians injured with five years. Another phenomenon of the site is a high fatality rate of seniors, so now it is located in the planning regulation zone of the safe street for seniors. The top cause of safety issues of the area is unsafe crossing, speeding vehicles, and vehicles do not yield. Other is loading activities and illegal crossing that people are crossing against signals or outside islands. Loading activities create double parking that block the view of both drivers and pedestrians. (NYCDOT, 2015)

To solve the problems, the major improvements of the site is the reduction of lanes, fixing the layout around central Broadway Mill. The travel lanes have reduced from 3 to 2 to enlarge parking lane for trunk loading and create a buffer around center Broadway Mill. A 6 feet buffer has established around Mill and extra pedestrian refuge is created to enlarge landing space. Other improvements for safety are implementation signs for left-turn vehicles and updating crossing signals.

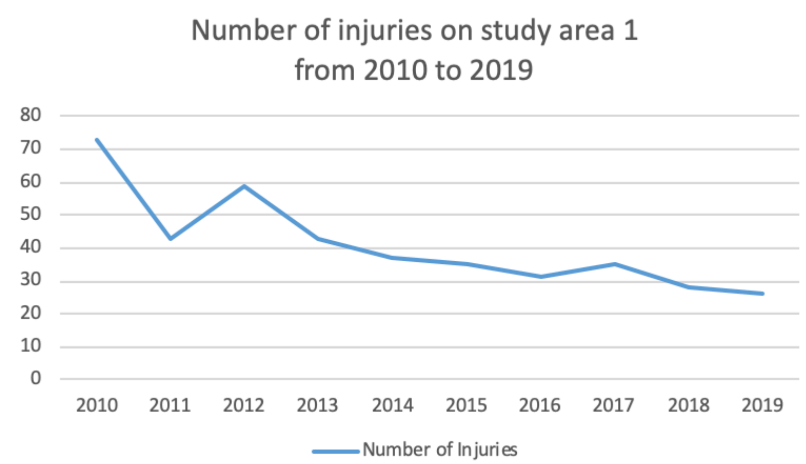

Figure 19: Number of injuries on study area 2 from 2010 to 2019

The figure 19 illustrates the number of injuries on study area from 2010 to 2019. Although there is some fluctuated increase, the main tendency of number of accidents is decrease. From 73 total injures in 2010 to 26 injuries in 2019, the number has reduced 64%. At 155th street intersection, the number of injures has decrease from 19 in 2010 to 3 in 2019. (Vision Zero View, 2019)

Site Observation

The pedestrian flow at the site is not large but a diversity of user groups could be seen that different age groups, race and income level. The central Broadway Mill is a unique factor of the site. People relax and rest in the green space. However, they sit on not only the provided bench but also the curb of green space which is really dangerous. The necessary buffer zone has been shown at this point. Two problems I notice at the site are not enough turning space and requirement of bike lane. An extra turning lane is in need of the site that too many left-turn vehicles create disorder of traffic. Another is on Saturday afternoon, lots of teenagers bike around the area, but there is no bike lane. They cycle at travel lanes and sidewalk create potentially dangerous for both themselves and other pedestrians. Refer back to the sidewalk question of data analysis, the sidewalk might a little too larger than the needs that not enough pedestrian flow on the site. A large sidewalk could reduce visibility of pedestrians due to far away from curb. My personal experience is it is a little hard to see the travel lane from center of the sidewalk due to large side and double parking. Planners could transfer part of sidewalk to another parking lane for freight.

Land Use: Commercial

8th Avenue between 34th Street and 45th Street

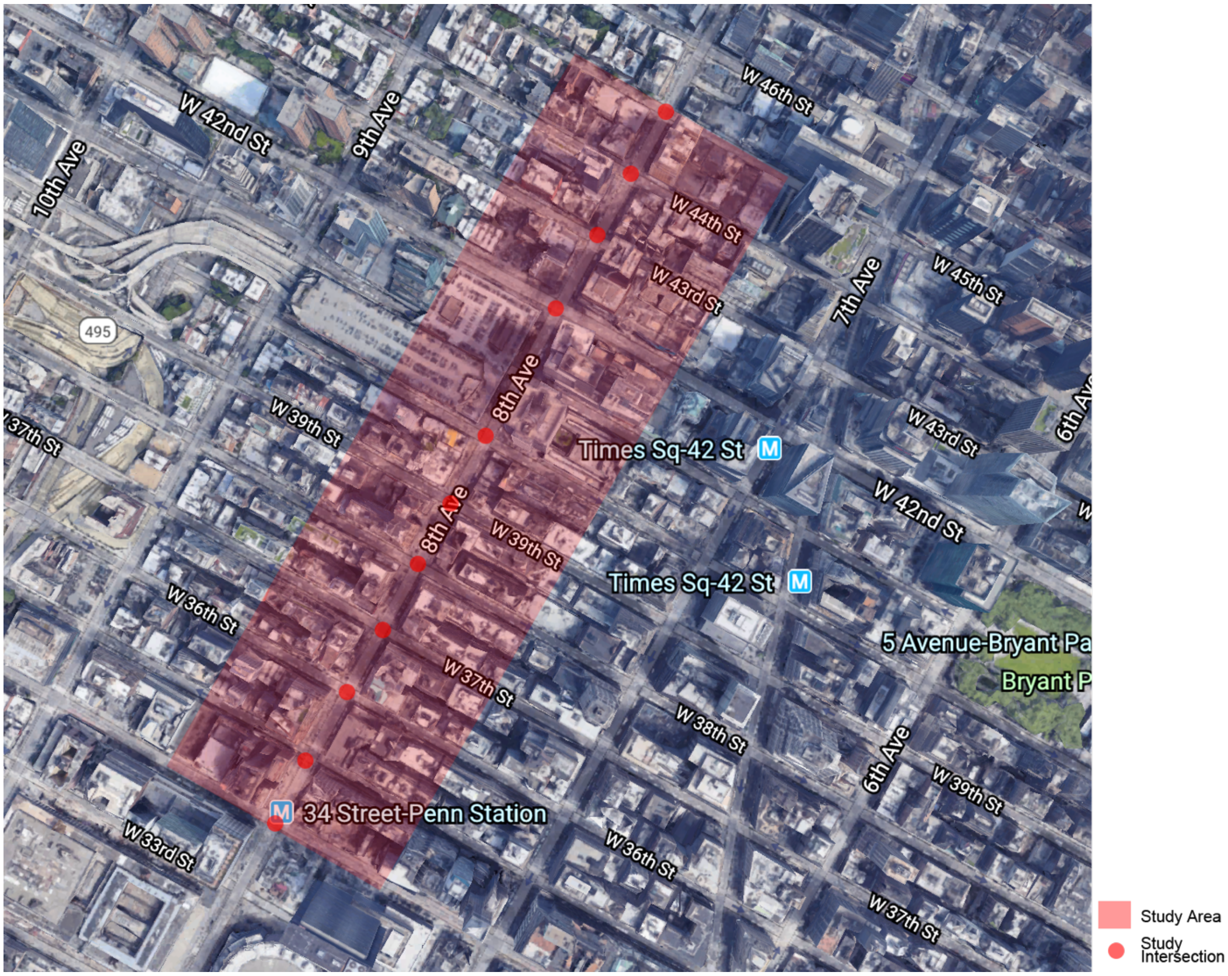

Figure 20: 8th Avenue between 34th Street and 45th Street Study Area

Project Description

8th Avenue from 34th Street to 45th Street is a key corridor connecting pedestrians from Pennsylvania Station to Port Authority Bus Terminal with commercial, office and entertainment land use. The issue at this site is pedestrian overcrowding and the unbalancing between sidewalk and travel lane. Due to high pedestrian density on-site, pedestrians usually walk outside of the sidewalk and one the travel lanes. The community requests to renovated and expanded sidewalk and establish continuation bike lanes on 8th Avenue.

Take a look at the peak hour travel method of 8th Avenue. At PM peak hour of one day, total of more than eleven thousand people walking on the street that share 85% of the total road users. On the other hand, the vehicle flow is only 1,600 that a shared 12% travel method. However, the street design of 8th Avenue is vehicle priority that vehicles shared 70% of the roadway, pedestrian with 30% and no bike-related roadway presented. (NYCDOT, 2018)

This unbalancing scenario could not serve the community that causes pedestrian overflow and walk on curbside lanes, which become potential unsafe factors. Inappropriate lane separation is the cause of the problem that the size of travel lanes is too large that around 11’-13’. The limited proposal size of each automobile used lane (travel lane, taxi stand and bus stop) to 10’ to give more space for bike lanes and sidewalk enlargement. Also, a green buffer will be provided for safety improvement. After the renovation, the pedestrian share of roads increased to 41%, vehicle fall to 50% and another 9% bike share is provided.

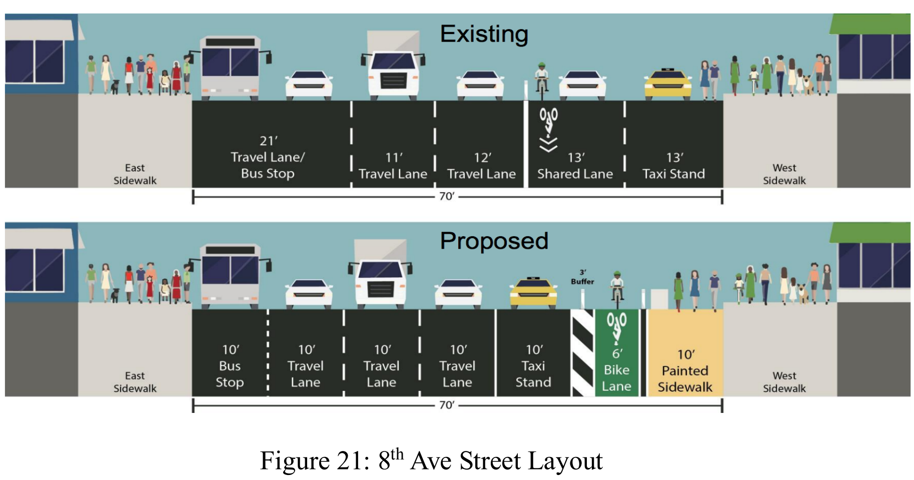

Figure 21: 8th Ave Street Layout

The absolution accident number of this study site is really large that 91 injuries in 2016 and 78 injuries in 2019. (VZV, 2019) This is the most famous part of New York City; the pedestrian flow is really high and cause a high number of accidents. Although the total number is continue fluctuated on the site. But look at selected intersection (figure 22) that 34th street, 42nd street and 43rd street which with improvement implemented it has a tendency of decrease from 2016 to 2019.

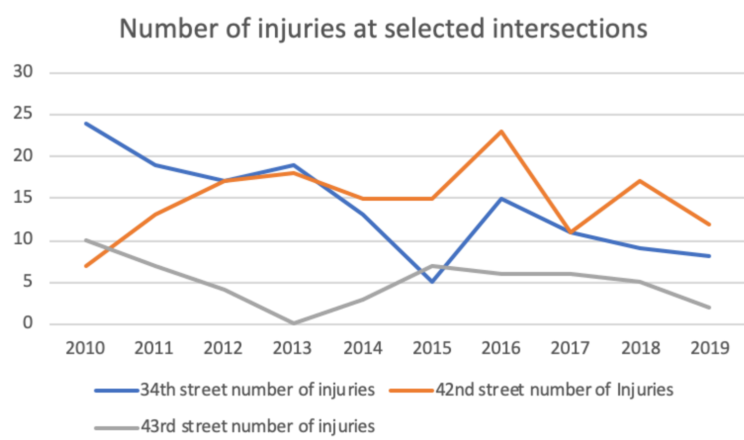

Figure 22: Number of injuries at selected intersections in Study Area 3 from 2010 to 2019

Site Observation

The site is close to port authority and time square, the pedestrians' and vehicles' flow is really high. The most direct notice is the high density of sidewalk that full of people. Compared to other sites, pedestrians most are tourism or young people that rare families or seniors. Planners still need to pay attention to the conditions that tourism is not familiar with the site. A clear sign and high maintenance are required. On Saturday afternoon, the travel lane is kind of empty but could imagine the business of the street at commute time. For crossing, because this is a busy street, most people crossed with the crossing signal and on a crosswalk. But due to high pedestrian flow, people will stand to the edge of the sidewalk as close as possible and also step to the pedestrian refuge. One unexpected dangerous factor at this site is the bike lane. Because bike lane is between sidewalk and pedestrian refuge, amount of people does not realize there is a bike lane in between and could not notice bike pass through.

Conclusion

Several problems have been detected from site observation that could not be observed from data analysis, which includes illegal crossing, lack of maintenance, large seating space. Also, site observation helps us identify the needs of the site that major users and existing conditions of the site. Refer back to the two questions from data analysis, though I still not 100% sure answering that requires more research, I have got some inspiration from site observation. For the partial implementation that could worsen safety, after site observation, I want to agree with the statement. Drivers and pedestrians use pedestrian refuge, curb extension and extra turning a lot. From study area 2 that Broadway and 145th street, the intersection without actual extra turning is lack of order. Sometimes turning vehicles, straight vehicles, cyclists, and pedestrians meet together at the center, which becomes a potential unsafety factor. Only a five minutes visit on the site, I have already noticed the issue. Also, drawn pedestrian refuge is not functional. I notice cars directly parking on it, which is hard to notice by drivers in the dark or driving fast. But pedestrians are like to stand on it. Tragedy will happen. So partial implementation will worsen the safety condition for sure that perfect implementation is required.

For the sidewalk question, further research is required. Numbers of unexpected things happen on the sidewalk that related to the behavior of people, time and weather, and business activities. A more detailed limitation will present in the next chapter. Nevertheless, from observation, for sure, sidewalks are a crucial element of human life, which could not be eliminated following the data model. The model is an idealist and theoretical result. We need to go back to the real world to exam it.

Chapter 6: Conclusion

Limitation and Future Study

I have mentioned it at the end of the last section. Due to the limitation of time and ability, there are limitations of this research that future studies could be conducted based on this methodology. The major improvement of the research is a more reliable data source, larger sample size, and more independent variables.

First of all, a more reliable data source could significantly help improve the result. Because of the lack of accessibility, current lane layout information is from the satellite view of Google. If research with enough time, labor, and cost, on-site measurement of each intersection with direct measurement of size could help improve the accuracy of the research. Similar logic could apply to a larger sample size. The large sample size is the most direct and easiest way to minimize the error of the regression model. The sample size in the research is 95 intersection with fatalities or more than ten injuries. If possible, a general analysis could be conducted with all 250 intersections in Manhattan, and even intersections at citywide. The analysis could involve both the most dangerous intersections and the safest intersections from two sides to exam the influence of design methods and planning strategies on safety improvement.

More independent variables could significantly improve the model from a more comprehensive theory. From site observation, I have concluded sidewalk is not independent from human life and environment that neighborhood condition, exiting conditions, time and weather all influence the presence of sidewalks. The theory also could apply to the safety condition. For my model, injuries and fatality are the best variables that reflect the safety condition. However, apart from design methods and planning strategies, other elements will directly or indirectly influence the safety, like social background, population demographics, time and weather, and condition of the street. Some of this idea has been reflected in my site observation that I controlled weather and time among three sites to conduct the observation. This idea is also needed for data analysis that controls time and weather that accident happened. Also, a street with a high vehicle and pedestrian flow, the accident will be easier to happen. When the model includes as much as independent variables, more prerequisites could establish and more scenarios could create. Therefore, the model will be more accurate.

Last, as a part of further research, how to make data models more practical is crucial for the next step. By solving this question, the problem with the sidewalk in my model could be eliminated. More independent variables could help improve the practicability of the model. On the other hand, improving the accuracy of each independent variable also could facilitate the result. For example, first exam the sidewalk size value that finds the most optimum level of sidewalk size to prevent it becomes out of context. Some indirect variables of the safety condition could include in the model for sidewalk sizes like business activity and diversity of users. This theory applies to all the independent variables to improve the accuracy of the model.

Discussion and Recommendations

From the analysis, although some limitations present, a basic safety improvement framework could be created. For a comprehensive and accurate analysis, nominal safety is much better than substantive safety that involves people's behavior and community condition into the examination. However, data analysis still is a crucial part of the research. It helps us quickly dealing with a large data set and a number of independent variables to narrow down the scope and reveal the issue. Although the hypothesis about the sidewalk in my model is not sophisticated, it still presented that most design improvements could improve the street safety condition. Pedestrian refuge, curb extension and extra turning care the most efficient methods. Only perfect implementation could help with accident reduction; on the other hand, partially implemented improvement might even deteriorate the safety condition. The regulation also could help with the scenario that Safe Street for Seniors is a great strategy.

Combining with site observation, we could conclude safety is not an independent factor. It relates to people's behavior and existing condition. The behavior of people is crucial to limit accident that no matter drivers or pedestrians and every people relate to streets. Planners should not only plan from model and number but, more importantly, from people.

The scale of the study is New York City, which is a representation of large cities in the world. A similar study could conduct in other cities with the same methods. Although some cultures and environmental differences might exist, the basic framework and methodology are the same. So, this safety improvement framework could be applied anywhere to improve street safety.

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Appendix: Independent Variables

Variable	Unit of measure	Data source
Number of fatalities	Total number of people fatalities at the intersection in 2019	NYCDOT – Vision Zero View
Number of injuries	Total number of people injuries at the intersection in 2019	NYCDOT – Vision Zero View
Sidewalk size	Average size in feet of sidewalks	Google Map's satellite view with measurement tool
Number of travel lanes	Number of travel lanes present on section view of the major corridor	Google Map's street view
Travel lane Size	Average Size in feet of each travel lane	Google Map's satellite view with measurement tool
Number of parking lanes	Number of parking lanes present on section view of the major corridor	Google Map's street view
Parking lane size	Average Size in feet of parking lanes	Google Map's satellite view with measurement tool

Bike lane size	Total bike lane size present on section view of the major corridor	Google Map's satellite view with measurement tool
Bus lane size	Total Bus lane size present on section view of the major corridor	Google Map's satellite view with measurement tool
Extra turning lane	Dummy variable 0 to 1	Google Map's street view
Protected bike lane	Dummy variable 0 to 1	Google Map's street view
Pedestrian refuge	Dummy variable 0 to 1	Google Map's street view
Curb extension	Dummy variable 0 to 1	Google Map's street view
Pedestrian lead interval signal	Dummy variable 0 to 1	NYCDOT – Vision Zero View
Arterial slow zone	Dummy variable 0 to 1	NYCDOT – Vision Zero View
Safe street for senior	Dummy variable 0 to 1	NYCDOT – Vision Zero View

Reference: New York City Department of Transportation. Vision Zero View. March 2020. Retrieved from http://www.nycvzv.info/